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Systems Analysis Department. Annual Progress Report 1988

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Publication date:
1989

Document Version
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ISBN 87-550-1487-9
ISSN 0106-2840
ISSN 0903-7101

Risø-R-565

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Systems Analysis Department Annual Progress Report 1988

Edited by Hans Larsen and
Gordon A. Mackenzie

Risø National Laboratory, DK-4000 Roskilde, Denmark
March 1989

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Abstract. The report describes the work of the Systems Analysis Department at Risø National Laboratory during 1988. The activities may be classified as energy systems analysis, risk and reliability analysis and environmental modelling. The report includes a list of staff members.

ISBN-87-550-1487-9
ISSN 0106-2840
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Grafisk Service, Risø

Contents

1. Introduction

The most important development in 1988 regarding the scope of work of the Systems Analysis Department was a growing emphasis on environmental questions. This involved a diversification of the work of the Energy Systems Group (ESG) towards environmental planning and economic analysis of environmental effects, and the establishment of the Environmental Modelling Group (EMG) on 1 February 1988. Another important development in 1988 was the intensification of the work of the Risk Analysis Group (RAG) on reliability and preventive maintenance.

The activities of the Systems Analysis Department in 1988 involved a continuation of the research related to the development of risk and reliability models, and energy-economy models. The expertise of the department was utilized in connection with several studies dealing with risk assessments, energy planning, and technology assessment.

Postgraduate research projects are an integrated part of the basic research of the department, and five such projects were in progress in 1988. A study concerning project planning and analysis methods for assessment of rural energy projects in developing countries was completed during the year. Two ongoing projects concern methods to predict the atmospheric dispersion of accidentally released chemicals, and analysis of the channels of interdependence between industrial and developing countries. Finally, two new post-graduate projects were initiated during the year and concerned hazard identification at plant level and economic analysis of energy and environmental effects.

The activities of the Energy Systems Group in 1988 involved R&D concerning advanced forecasting and simulation models as well as specific studies carried out in collaboration with industry and public authorities.

The research and development activities of the group included a continuation of the work in connection with the energy systems analysis programme of the Commission of the European Communities (CEC) dealing with the Danish national version of the macrosectoral model (HERMES), the European version of the Danish Energy System model (DESS), and the energy flow optimization model (EFOM) with an environmental extension. Work was continued on the development of technoeconomic models in the oil and gas sector to be used in connection with field developments in the North Sea.

A number of environmental planning projects have been initiated during the year. These deal with the cost effectiveness of emission-reduction measures in the space heating sector in Denmark and an evaluation of methods used for energy and environmental planning in the Nordic countries, as well as a project on integrated energy and environmental planning for the island of Bornholm. In addition, the group has become Danish participants in the CORINAIR project for the CEC. Finally, a study was carried out regarding the environmental consequences of the building of the Great Belt Fixed Link.

The Energy Systems Group collaborates closely with the Danish Ministry of Energy and the Danish Energy Agency on Danish energy planning. The work in 1988 included contributions to the Status Report on Energy Planning, especially regarding the Danish response to the report of the UN Commission on Development and the Environment, the so-called Brundtland report. The activities concerning wind-energy economy and prospects for absorption cooling have been continued, and a new project dealing with low temperature problems in sewage treatment plants was initialized.

The Risk Analysis Group is engaged in R&D on reliability and risk analysis methods and tools, conveyance of know-how on these to industry and authorities, and the performance of specific risk analysis studies in collaboration with industry and public authorities.

The research and development activities of the group included continued participation in the European benchmark exercises on structural reliability and event sequences, while work on a new benchmark exercise on major hazard analysis was initiated in 1988.

The development of a new tool for computer aided risk analysis (STARS) was continued in collaboration with JRC-Ispra and others, as was the work on risk analysis within the research programme of the Nordic Liaison Committee for Atomic Energy. Within the CEC-programme on Major Technical Hazards a project dealing with physical modelling of torch fires has been supplemented by the performance of preliminary pilot experiments.

The group is participating in a Nordic research programme on terotechnology initiated during 1988. The objective of this programme is to improve reliability and reduce maintenance cost for industrial equipment.

Several specific risk analyses have been performed for chemical industries. Within the oil and gas sector the analysis of the security of supply of the Danish natural gas transmission system was completed, and a project on guidelines for risk analysis of offshore installations was carried out. The study on reliability of smaller windmills was continued, and an overall risk analysis of the Great Belt Fixed Link was initiated.

The overall aim of the work of the Environmental Modelling Group is to develop models which can contribute to presenting a complete picture of the total effect of pollution on the environment.

The research and development activities of the group in 1988 have been dominated by the completion of the project: Development of a computer model for the evaluation of environmental effects of different energy supply alternatives (ECCES), which was started in the Energy Technology Department in 1982. Work has also been initiated on the implementation and use of the RAINS model, developed by IIASA.

The majority of the tasks carried out in the Systems Analysis Department involve close collaboration with Danish and foreign companies, consulting firms, public authorities, and international organisations e.g. the Danish Ministry of Energy, the Danish Energy Agency, the National Agency of Environmental Protection, the Nordic Council of Ministers, and the Commission of the European Communities.

In 1988 a programme committee was established for the Risø International Conference on Environmental Models: Emissions and Consequences, which will take place from the 22nd to the 25th May 1989. The Call for Papers was issued during the year, and a preliminary programme for the conference was finalized by the end of 1988.

In 1988 members of the department participated in a number of Danish committees dealing with questions on energy, environment or risk analysis. In addition, members of the department have participated in international committees within the Nordic collaboration, The IEA, and the European Communities, and have presented papers at international conferences, workshops, and seminars.

2. Risk Analysis

The work in the Risk Analysis Group covers a wide range of activities aiming at fulfilling the requirements of society and industry for risk and reliability analysis of higher and higher quality. The activities include development of new methods of analysis as well as improvements of old methods such as:

- Development of computerized decision-support systems for fault-tree construction and consequence modelling.
- CEC-sponsored reliability benchmark exercises.
- CEC-sponsored field experiments on modelling of torch fires.
- Nordic Industrial Fund sponsored project on operational reliability and preventive maintenance.
- Development of guidelines for risk analysis of offshore platforms.

Furthermore the group was engaged in a wide range of analyses of industrial plants and installations: the Danish natural gas system, the natural gas storage, the Great Belt Fixed Link, smaller windmills and the Danish vacuum pressure impregnation industry.

The activities are described in detail in the following chapters.

2.1. European reliability benchmark exercises

The concept of reliability benchmark exercise was started within the nuclear area. The aim being to develop methods and tools for reliability analysis by letting different teams analyse the same problem and comparing and discussing results, differences etc.

The problems covered have been:

- system modelling
- common cause failures
- human error
- event sequence modelling.

The final exercise conducted in 1988 will be described in more detail below. Also included in the benchmark exercises was a structural reliability problem concerning pressure vessels.

Finally a non-nuclear exercise concerning an ammonia terminal was started. This exercise will also include consequence modelling.

2.1.1. Event sequence reliability benchmark exercise

A reliability benchmark exercise concerning an event sequence was started in late 1987 under the Shared Cost Action programme of the Commission of the European Communities. Teams from the following countries participate in the exercise: Belgium, Denmark, France, Germany, Italy, The Netherlands, Spain, Sweden, UK and USA.

The Event Sequence Reliability Benchmark Exercise is a logical continuation of a series of three previous exercises on system-analysis, common-cause failure and human factors.

The exercise concerns an incident in the same plant as the one dealt with in the two previous exercises, the German Grohnde PWR nuclear power station. The initiating event is a loss of offsite power and all subsequent sequences that could develop during a period of 14 hours and lead to core melt should be identified and analysed. The analysis will include both independent, common-cause and human failure events.

The first phase of the exercise was started in 1987 and was reported in 1988. The qualitative part of the analysis comprised the construction of the logical model for the event sequence. It was carried out by means of Risø's computer program EM (Event Modelling). The model applied consists of a series of failure block diagrams, which are equivalent to a cause consequence diagram. The EM program draws these diagrams and prepares the input to Risø's FAUNET and MOCARE programs, which were used for the subsequent calculations of the probability of a core melt.

The result of the first phase of the analysis was that the event sequence is totally dominated by a single failure event - that the operator fails to start the shut-down cooling of the plant. The probability of this human-error event turned out to be impossible to estimate using the prescribed HCR model. Risø's team estimated this probability to be 0.002 using Swains THERP method.

The second and last phase of the exercise will have a narrower scope in order to facilitate detailed comparisons of team results.

2.1.2. Structural reliability benchmark exercise

The structural reliability benchmark exercise concerns the reliability and structural integrity of pressure vessels. The participants are Risø, Framatome (France), Frauenhofer Institut, Darmstadt (FRG) and University of Karlsruhe (FRG). The project is within the Shared Cost Action programme and JRC-Ispra acts as coordinator.

A 1/5 scale vessel was fatigue tested and at approximately 350,000 cycles it leaked. The vessel contained natural as well as artificial defects.

Crack growth has been simulated directly on the basis of experimental data. The data comes from standard 1" CT-specimens and shows a very large scatter, possibly due to measuring uncertainty. Accordingly, the simulation has been performed using a "mean" and a "worst case" scatter.

Repeated ultrasonic inspections showed a similar pattern, i.e. very large differences between the inspection teams in sizing and location. Again a mean and a worst case were used.

2.1.3. Benchmark exercise on major hazards analysis

A study of major hazards associated with the operation of a chemical plant began in 1988 under the Shared Cost Action programme of the Commission of the European Communities.
Teams participated from the following countries: Belgium, Denmark, Finland, France, Germany, Italy, The Netherlands, UK and Spain.

The Danish participation in the exercise has taken form of a joint venture between the following four organisations: Risø National Laboratory, Cowiconsult Consulting Engineers and Planners A/S, OC Consulting Engineers and Planners A/S and Computational Safety and Reliability.

The first phase of the exercise included:

- hazard identification and ranking,
- evaluation of selected event sequences,
- evaluation of individual risk (outdoor and indoor conditions in the environment, risk contours),
- evaluation of the effect of a flare system,
- estimation of accuracy and uncertainty of results.

The first phase of the study was reported in late 1988. The Joint Research Centre, Ispra, has compared the results of the various teams with the purpose of seeing how the results vary with the choice of analysis strategy and models. This evaluation will be presented at a meeting early in 1989. At this meeting common assumptions to be adopted for the second working phase will also be defined.

2.2. Computer-aided risk analysis

2.2.1. The STARS project

The purpose of the STARS (Software Tools for Advanced Reliability and Safety Analysis) project is to develop an integrated set of advanced software tools to support the analysts working with safety and reliability analysis of chemical plants and power plants.

The STARS project is a collaborative project between Risø National Laboratory, JRC-Ispra, VTT (Technical Research Centre of Finland) and ENEA (Italy).

STARS is planned as a knowledge-based approach to systems safety and reliability analysis and to represent the next generation of programs, following RIKKE (developed at Risø) and CAFTS (developed at JRC-Ispra) for automatic fault tree construction. The STARS program will be able to perform the same tasks more effectively and in addition include some new tasks.

The tasks in the STARS program include:

- Initial data collection and updating. This includes description of the plant or system under analysis.
- Qualitative analysis. This includes identification of hazardous events or event sequences.
- Event sequence modelling for the structuring of the identified events and event sequences into logic models. This includes construction of event trees and master fault trees.
- Systems modelling for the construction of logic models for the system malfunctions that appear in the event sequences of event sequence models. This includes construction of fault trees and generation of state graphs or transition matrices.
- Model analysis. This includes logic and probabilistic analysis of the constructed models for systems and event sequences.

At Risø the development of the qualitative analysis module was initiated in 1988. A representative chemical plant (a nitric-acid plant) has been selected and a unit diagram of this plant has been constructed. From this basis a generic list of units and a generic list of parameter deviations has been performed. Furthermore, a draft of a chemical substance knowledge base has been created. The purpose of the above-mentioned work is to identify relevant hazardous events or event sequences and to exclude non-relevant events.

Hazard identification at plant level

A Ph.D. study concerning hazard identification at plant level was initiated in 1988. The project is carried out in collaboration with the Institute for Chemical Industries at the Technical University of Denmark.

The purpose of the study is to develop a method for hazard identification which makes it possible to:

- point out those areas of chemical process plants where further analysis is necessary,
- give an overall description of the risk associated with a chemical process plant.

There exist some methods for hazard identification at plant level, among these are: The Mond and Dow index together with IFAL (Instantaneous Fractional Annual Loss). In these methods the first step is a division of process plants into process units. Each process unit is then studied in further detail to estimate its contribution to the total hazard level of the plant.

In 1988 the methods have been tested on 3 chemical process plants, selected in such a way that they cover the majority of the hazards found in the chemical industry. The 3 plants are:

- A petrochemical plant,
- A fine chemical plant,
- A fertilizer plant.

The results of the studies show that fire and explosion are the types of risks which are best identified by the methods. Weaknesses of the methods are found to be:

- The probabilities are not sufficiently documented,
- Toxicological considerations are not included,
- The functional connections of the plant are not implicated,
- Human actions are not taken into account.

In general there was good agreement between the risk levels calculated by Dow and Mond index although, this is not surprising since the Mond index is a development of the Dow index.

When calculating the Dow and the Mond index it is necessary to make some individual estimations. Therefore a small sensitivity study has been carried out. The results show that:

- Three risk analysts obtained comparable results,
- No extremely sensitive parameter has been identified.

2.3. Consequence management models

A Ph.D. study initiated in January 1987 concerns the micrometeorological aspects of risk assessment. The purpose of the project is to investigate and develop methods to predict the atmospheric dispersion of accidentially released chemicals. The study is carried out in collaboration with Risø's Meteorological Department.

A jet/plume model called HEAVY/JET has been developed and has proved useful in practical risk analyses. The model is based on budgets for conserved quantities like mass, energy and momentum, combined with Monin-Obukhov similarity profiles for wind speed and temperature, and with an entrainment model that is tuned so as to conform with experimental results in both the near and far-field limits.

Figure 2.1. shows an example of the use of the model to analyse a vent stack placed on a natural gas plant. The plume is shown below inside-view and above the concentrations at the centre line of the plume is shown. The plume has a tendency to sink and will eventually make contact with the ground. The concentration is however already far beyond the lower limit of flammability 100 m downstream of the stack, and here the plume is still elevated.

During a hazard and operability (hazop) analysis the question was raised whether an ignitable heavy gas blanket could form as a result of the cooling caused by depressurization of the gas during blow-down. Preliminary calculations showed that this behaviour can only be expected if the enthalphy is very low and, at the same time, meteorological conditions are unfavourable. It was therefore decided to make an experimental test of the blow-down system in order to check outflow rates and measure temperatures inside the process equipment during a blow-down. It turned out that the heat transfer to the gas is appreciable, so that the enthalphy is not nearly low enough for an ignitable dense cloud to form.

The Commission of the European Communities has initiated a research programme on "Major Technological Hazards" in which Risø takes part. One of the subprogrammes is concerned with the effect of obstacles on the dispersion of heavy gasses. Among the activities are full scale experiments that are carried out by the Meteorological Department at Risø and TÜV in collaboration.

Participation in the preparation of the experiments and evaluation of the data is part of the Ph.D. project. The purpose of the experiments is to study the effects of a linear fence on the behaviour of a dense cloud made by releasing substantial amounts of cold propane. The data are collected with catalytic sensors, infrared sensors, fast thermocouples, cup anemometer as well as video and photography. It is also possible that a LIDAR will be set up in future experiments. So far most of the work has been concerned with designing and building instruments and explosion proof power supplies, and with the data collection system. A new technique is used to obtain fast sampling of concentrations based on a sonic anemometer and a fast thermo sensor. The anemometer essentially measures the speed of sound in three directions, from which the components

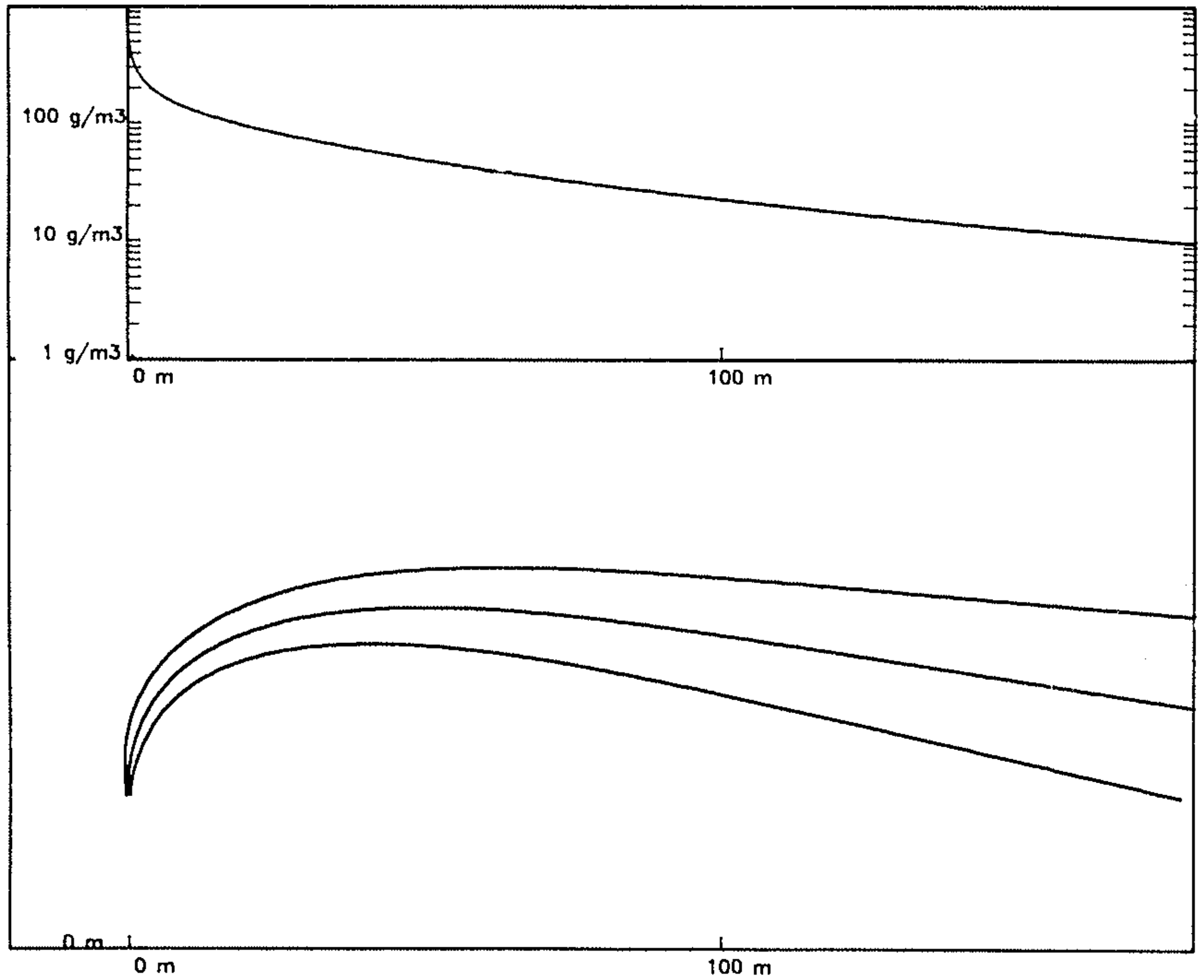

Figure 2.1. Output from the program HEAVYJET.

of the wind field and the temperature can be deduced. The presence of propane will, however, "fool" the instrument because the speed of sound is changed by the propane. The propane concentration can therefore be calculated if the true temperature is known. A preliminary series of experiments was carried out in the autumn of 1988 to make visual observations and to test the instruments, the data collection system and the fence which can be lowered in order to allow comparison with the unobstructed case. The results of the tests were very satisfactory.

The dilution of a contaminant in the atmosphere is totally governed by turbulence, so the understanding of turbulence is a key to the solution of dispersion problems. Therefore the Ph.D. study has a theoretical part. Here methods are studied that attempt to deduce the statistical structure of turbulence from first principles. It has been found that the mathematical description of the behaviour of an ensemble of realisations of a flow can be brought to a form that closely resembles that of a quantum gas of interacting bosons. This description also includes the dispersion of a containment. The idea is to take advantage of this analogy and exploit methods that have been developed for quantum systems. In particular the Feynmann graph technique can be copied, and it is found that some otherwise known results can be obtained within this more general framework as low order approximations.

As a part of the CEC-programme "Major Technological Hazards" a project has been initiated with the aim of attaining reliable modelling techniques for obstructed/unobstructed gas diffusion flames. Within this project termed "Physical modelling of torch fires" the System Analysis Department is responsible for conducting large-scale experiments to provide data for development of models. Measurements will include temperature field within the flame, heatflux field around the flame and flame geometry. In 1988 design and preparation of the first stage of the experiments has taken place. A test-site in open air within Risø has been set up, consisting of a 60 m diameter plane area. A burner for creating horizontal flames with a maximum length of 10 m has been designed and manufactured. The temperature field and heatflux-nearfield of the flame will be measured by means of equipment mounted in a frame to be moved along the flame, while surrounding it.

Experiments commence early in 1989. Guided by the results design will be made of the next stage (flames up to 30 m in length).

The COMA programme has been brought one step further towards realization: Models for testing the basic COMA concepts have been set up (liquid leaking from container, spreading liquid pool with time-varying inflow). Programming the central core has begun.

2.4. Terotechnology

A Nordic research programme on terotechnology has been initiated. The objective is to achieve a better reliability and a reduced maintenance cost for industrial equipment by:

- development of methods for accelerated life testing, condition monitoring and treatment of operational and failure data, especially in the communication between designers and users,
- improving the competency to apply these methods in industry.

Figure 2.2. indicates the interaction between design, research and production in this problem area.

The research programme is divided into four research areas one of which deals with availability performance assurance. Risø contributes to this research area with two projects:

- A technical/economical system for maintenance of industrial plants.
- Exchange of information between designer and user of industrial plants.

In the first phase of the programme period work has been concentrated on the preparation of a detailed project description and discussions with Danish industrial partners on involvement in the projects.

2.5. Risk analysis, NKA

Risø participates in the project "Risk Analysis" within the Nordic Liaison Committee for Atomic Energy (NKA) Research Programme. The work in 1988 has concentrated on two subjects:

- a reference study on human interactions in accident conditions,
- a benchmark study on treatment of uncertainties in probabilistic risk analyses.

The reference study comprised an analysis of an accident sequence at a Swedish nuclear power plant. The qualitative analysis and an exercise of the sequence at the Swedish operator training simulator was finalized in 1987. A subsequent quantification was performed and documented in 1988.

The main conclusions were that the HCR model used was not adequate in the analysis of this sequence, since the time needed for the operators to perform their task was very close to the time available, giving obvious misleading numbers close to unity.

Furthermore, it was recommended that the safety instructions for the operators be improved, since the probability of misdiagnosis was the main contributor to failure of the operator task.

The benchmark study on treatment of uncertainties is carried out with the aim of evaluating the impact of data uncertainties. The sequence is loss of off-site power, loss of the auxiliary feed water system, and failed operator initiation of the manual depressurization (the sequence in which the human intervention was described in the reference study above).

At Risø the MOCARE simulation program was modified in order to treat data uncertainties. The input was a fixed list of 88 cut sets with specification of distribution characteristics for

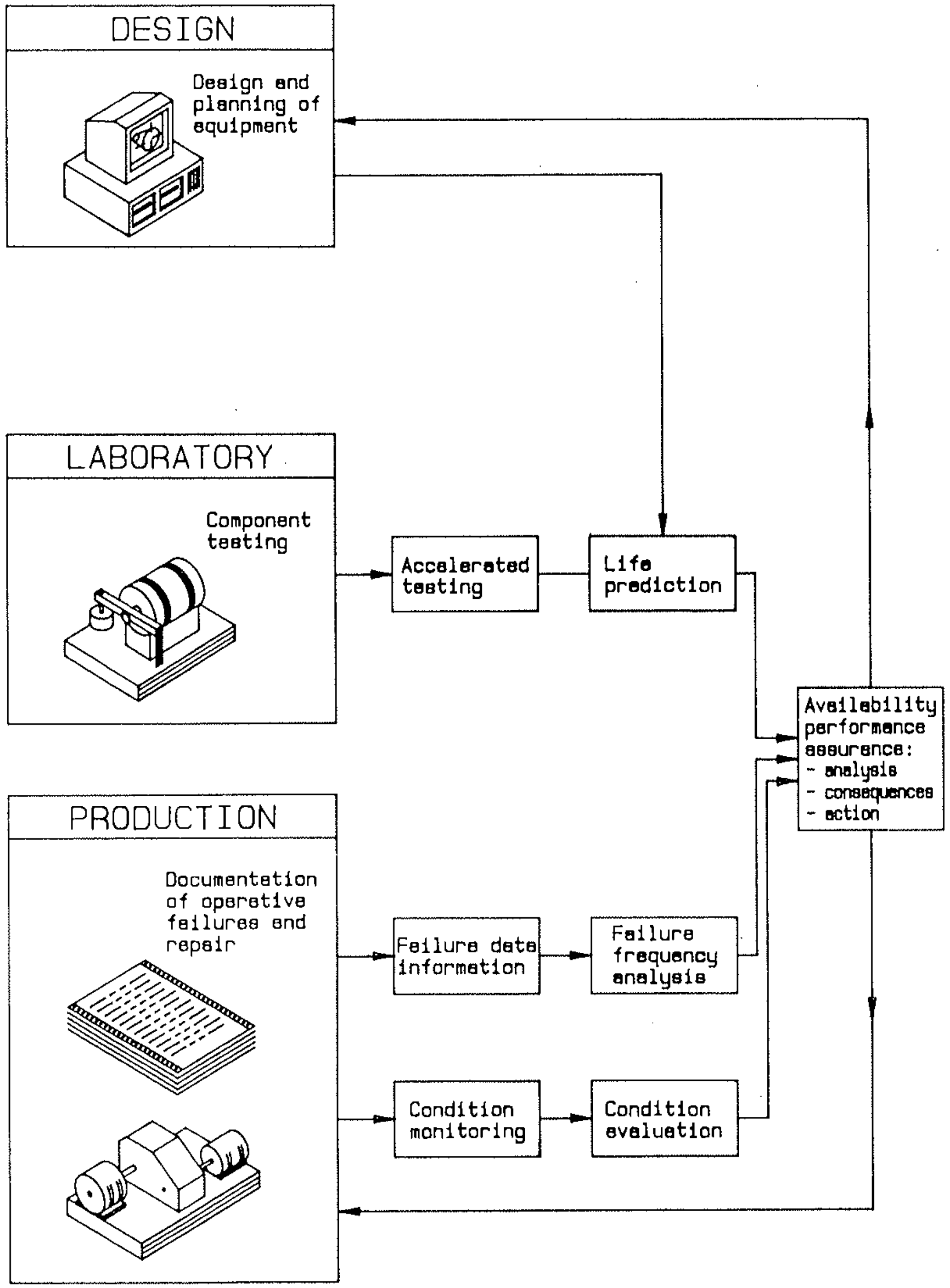

Figure 2.2. Methods for increasing operative reliability.

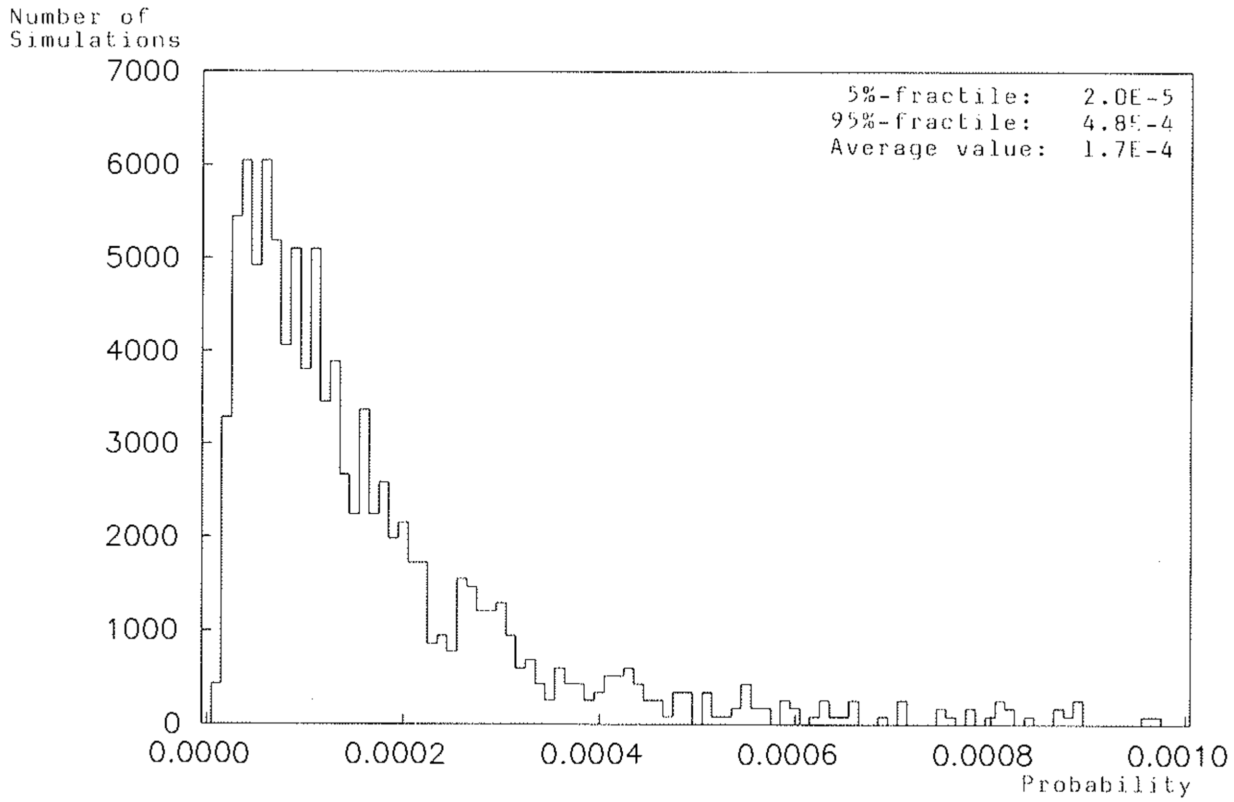

Figure 2.3. Distribution of system failure probabilities.

the 18 basic events. An example based on a common data set is shown in Figure 2.3.

It is seen that there is a large variation. A factor of 24 between the 5th and 95th percentile is observed and the average value in agreement with standard point estimates. A set of simulations with varying data will be calculated in 1989.

2.6. Hazardous Materials

A research project concerning combustion of chemical substances has been initiated as it is important to have information on this subject in connection with risk analyses of chemical plants and storage facilities. This involves information on:

- which toxic gases can be generated by combustion of the chemical substance and in which amount
- how much of the original chemical substance is entrained in the plume
- the influence of the temperature and oxygen supply.

A search in the accessible literature has been performed. Furthermore, pilot experiments have been carried out in the laboratory in order to construct an experimental set-up and to develop qualitative and quantitative analysis methods.

A data base containing information on hazardous chemical substances has been created. The available information on the substances in the data base is:

- Chemical Abstract Service (CAS) number
- International Union of Pure and Applied Chemistry (IUPAC) name
- Physical and chemical properties
- Toxicological information.

Several ways of searching in the data base are possible, e.g. after CAS number, formula, common name etc. It is also possible to list the substances in the data base with a specific property, e.g. carcinogenicity or flammability.

At the moment the data base contains information on chemical substances examined in previous risk analysis studies.

2.7. Risk management

The Risk Committee of the ATV (Danish Academy of Technical Sciences) is working on the promotion of Danish risk research and risk management. Two members of the risk analysis group participate in the work of the committee.

A case from 1986-87 involving a new herbicide production plant at Kemisk Værk Køge has been studied by the committee, because this case attracted wide public interest and brought a demonstration of the difficulties involved in risk management. The study was reported in 1988 by ATV.

A series of newsletters from Teknologinævnet (Danish Technology Information Board) covers selected technological topics in a human and social context. During 1988 these newsletters included a special issue on risk evaluation, edited by a member of the risk analysis group.

2.8. Offshore oil and gas

The natural gas storage facility in Lille Torup was analysed in collaboration with N&R Consult.

The analysis focussed on the cold vent which relieves pressure (and gas) from the process area in case of emergencies. Also during normal operation, such as shutdown, repair, maintenance etc., the vent is used for manual blowdown. Pressures in the plant range between 80 and 220 bar and the gas volume amounts to 20,000 m^3.

Preliminary calculations showed that temperatures in the plant during a blowdown would be as low as -100°C. Such temperatures would endanger the integrity of the piping and the gas released would behave as a heavy gas. Accordingly, a full-scale test was performed and temperatures and pressures were measured. The test showed that gas temperatures only reach -50°C indicating that integrity can be assumed and that the gas will behave as a light gas. Finally a total blowdown was assumed to be ignited and the radiation levels were calculated on the basis of guideline API521. The resulting radiation levels at the fence are higher than allowed and different cures are being considered. These include moving the vent or sequential blowdown.

A project concerning development of guide lines for risk analysis of offshore installations in the Danish sector of the North Sea has been started on request from the Danish Energy Agency. In 1988 a first draft of the new guidelines was made on the basis of the guidelines of the Norwegian Petroleum Directorate (NPD). These guidelines have been used earlier in risk analysis of Danish offshore installations. The main changes proposed by Risø (compared to the NPD guidelines) are: more emphasis on failure analysis and analysis of human errors, less emphasis on fixed quantitative acceptance criteria and, in general, a higher priority to holistic risk analysis combined with in depth analysis of a subset of relevant hazards.

The project on analysis of the security of supply of the Danish natural gas transmission system has been completed. The work comprised separate studies of each part of the system aimed at identifying loss-of-supply events and estimating their probability and duration. The data used in the analysis were collected from earlier studies, available reports and from discussions with gas-distribution companies in Norway, Germany and the Netherlands.

2.9. Risk analyses for the chemical industry

The EC directive on "Major Accident Hazards of Certain Industrial Activities" has been adjusted to Danish legislation and implemented in Denmark. Therefore, a number of chemical plants are now required to submit risk analyses of their activities.

In 1988 the Risk Analysis Group performed risk analyses of 22 almost identical pressure impregnation plants. According to Danish legislation a risk assessment must be carried out for plants using or storing more than a specific amount of arsenic compounds. This is the case for the pressure impregnation plants using CCA (Chromated Copper Arsenate).

The project was structured as follows: One of the plants which was representative of the 22 plants was selected as model plant and a detailed risk analysis was performed. On this basis a model risk analysis was carried out, involving a technical description (topography, equipment

and materials), hazard identification, calculations of the consequences and recommendations. The most important hazards identified were releases of:

- toxic gases by fire
- ecotoxic substances by the fire-fighting water.

Finally the 21 separate risk analyses were carried out. Only the important differences were analysed, otherwise reference was made to the model risk analysis.

2.10. Reliability of smaller wind turbines and economic consequences

The project within the Danish Energy Research Program on reliability of smaller wind turbines and economic consequences was continued in 1988.

In the first phase an evaluation of publicly available operating experience was performed. The main conclusions were:

- the failure rates for separate wind turbines are comparable
- the failure rate for separate systems in a given design (yaw system, gearbox, generator, etc.) varies, but there is no significant difference in the failure rates for the same system in different designs.

The conclusion of the statistical tests performed is that subsequent analyses can be limited to study of one design.

In the second phase the wind turbine was divided into 12 subsystems. For each subsystem a fault tree describing the relationship between failures of single components was constructed. Furthermore, the dependencies between components and subsystem are to be modelled.

In the third phase an analysis of failure reports for the selected wind turbine design was performed. The data which can be estimated from the analysis had to be supplemented by generic data, since the experiences documented are scarce and imcomplete.

The final report of the project is being prepared and will be finalized in early 1989.

2.11. The Great Belt Fixed Link

The link will consist of three main parts: A railway tunnel from Sjælland to Sprogø, a road bridge from Sjælland to Sprogø and a combined rail and road bridge from Sprogø to Fyn.

In collaboration with Cowiconsult A/S and Rowe Research Engineering Associates (USA) an overall risk analysis was performed based on operational risk analysis for the different parts. All aspects of risk were addressed:

- Individual risk to users.
- Societal risk.
- Risk of disruption.
- Risk to third parties and the environment.

A set of acceptance criteria covering these aspects was established. For the individual risk the acceptance level was linked to the individual risk on open modern rail and road. The incremental risk to users was set to a fraction of the statistical scatter during the last 10 years.

The acceptable societal risk was established on the same basis but with the inclusion of risk aversion factors, i.e. lower probability for higher consequences (number of fatalities).

The acceptable level for disruption was fixed so that the probability of a disruption lasting more than a month should be less than 10^{-4} per year (i.e. 10^{-2} for a 100 year lifetime).

Probability and consequences of accidents were assured. The accidents considered included: ship impact and dragged anchors, derailment of trains, hazardous materials (rail or road), earthquake, ice loads, flooding, etc.

Uncertainties were addressed throughout the analysis. In the next phase several accident scenarios will be analysed in detail and the consequence models will be refined. Also terrorism and sabotage will be assessed and a safety management system will be established.

3. Environmental modelling

The Environmental Modelling Group (EMG) was established on 1st February 1988, in the Systems Analysis Department. The overall aim of the work is to develop models which can contribute to presenting a complete picture of the total effect of pollution on the environment. A better knowledge and understanding of the connection between the activities of society and the potential damage to the environment can facilitate the introduction of measures to reduce the impact most cost-effectively.

More specifically, the immediate aim of the group is to develop and use tools which can represent the environmental impact of energy conversion at a level of detail which is sufficient to make planning decisions by relevant bodies. In addition the models should if possible be able to deal with other environmental effects, for example from natural causes and from agriculture.

The main work of the EMG in 1988 was the development of the ECCES (Environmental Calculations of Consequences from Energy Systems) model which was originally initiated in the Energy Technology Department and financed by funds from the Danish Energy Research Programme.

The basic elements of the ECCES model were constructed during the EFP-82 and EFP-84 periods. After the initial development phase the model could be used to calculate the atmospheric dispersion of selected pollutants, their deposition on land, their effect on soil chemistry and uptake in plants. In the subsequent development phase under EFP-85 the model was extended and improved and the predictions of the model were compared with experimental measurements. This led to further improvements in the model.

The next phase under EFP-87 is concerned with the application of the model to forest soils. The aim is to gain experience with the model in a realistic context, by comparing results with measurements from forest soils.

The Environmental Modelling Group has recently prepared a document outlining its plans for future work. These include the further development of the ECCES model as a flexible integrated planning tool, the implementation, development and use of other complementary models (e.g. RAINS). In line with these developments a PhD research programme will start on 1st February 1989. The subject of the project will be the modelling of qualitative changes in aquatic systems brought about by pollution.

3.1. Development of the environmental-impact model ECCES

The computer model ECCES (Environmental Calculation of Consequences from Energy Systems) has been developed during the past six years with support from the energy research programme of the Danish Ministry of Energy. The model was originally developed in the Department of Energy Technology in close collaboration with the Chemistry Department. This latter collaboration has continued since the project was transferred to the Systems Analysis Department.

As its name indicates, the purpose of the model is to calculate the environmental consequences of energy production. More specifically this means the acidification of soils when subject to acid rain, although the model can, in principle, be extended and used to calculate other processes within the environment.

ECCES is a so-called integrated model which contains information about both the source of pollution, in this case energy production, and the receptor. The main concentration in the model, however, is on the processes which occur after the pollutant, acid rain, has reached the ground.

The model contains submodels for atmospheric dispersion and deposition of pollutants, soil chemistry and uptake of pollutants in crops. Dispersion of pollutants from power stations and area sources is calculated using a traditional plume model which is valid for deposition at locations up to 100 km from the source. The soil chemistry model calculates chemical equilibrium between adsorbed and soluble ions in the soil layers. The cation exchange capacity of the soil is separated into a permanent and a pH-dependent part. Ion uptake in crops is assumed to be proportional to the equilibrum concentrations in soil water.

The results of the model thus consist of the concentrations of various ions in the soil water and in crops. The model can be used to explore how these concentrations vary over time subject to pollution from particular energy scenarios. At present the model is best suited to the study of relatively local consequences, up to 100 km, of a fossil-fueled power station, but in principle the impact of longer range transport can be included.

The work on the model in 1988 was concentrated on the completion of the project financed by the 1985 energy research programme. This phase of model development involved verification of the model through comparison with laboratory measurements, improvement of the model in the light of these experiments and extension of the model to deal with forest systems.

Until now the model has been able to deal with the processes which occur when acid rain falls on bare soil or agricultural soil with low vegetation. The extension for forest soils meant the construction of modules to simulate the changes which occur in the composition of rainwater when it comes into contact with the foliage and branches of trees and with the deposited litter (dead leaves, branches, etc.) on the forest floor.

The modelling of the forest system has been kept at a very simple level in the first instance. For example is the forest assumed to be static in that no net annual growth is assumed. Seasonal variations in leaf area are however included.

Neither direct nor indirect damage to the trees is included in the model at the present time. The main objective for the time being is to include the processes which are relevant for the subsequent project described in the next section. The model will be extended when appropriate.

In addition to the extension of the model, the software has been rationalised and improved. In particular an effort has been made to increase the user-friendliness and flexibility of the program.

3.2. Application of the soil chemistry model to forest soils

As described in the previous section the ECCES model has been extended with a forest module. The purpose of this new module is mainly to calculate how the input of water and ions to the soil is changed because of interactions in the canopy.

The aim of the project under the 1987 energy research programme is to use the model in connection with field experiments in order to verify the model and interpret the experimental results. The project is carried out in cooperation with the Danish Forest Experiment Station, Danish Environmental Research (Air Pollution Laboratory) and the Chemistry Department (Risø).

The first two institutions are responsible for the field experiment which involves measuring the amount of rainwater, through-falling water and litterfall, besides taking samples of soil and soil water at different depths. The Chemistry Department performs the analysis of water samples and characterization of soil samples.

In 1988 the work has focused on the experimental part in order to obtain data to be used in the modelling. In the start of the year equipment for collecting different samples was established and in the rest of the year samples were chemically analyzed and characterized.

In 1989 it is planned to carry out modelling in parallel with the experimental work.

3.3. The RAINS model

During 1988 the RAINS model was implemented in the department. RAINS (Regional Acidification Information and Simulation) was developed at the International Institute for Applied Systems Analysis (IIASA) which is based in Vienna. The model is an integrated model of acidification in Europe designed for evaluating control strategies, see e.g. Alcamo et al. (1987).

The version of the model currently in operation links SO_2 emissions from all countries in Europe to the deposition and effects on lakes, soil and forests in Europe. The model can thus be used to explore the environmental consequences of emission control strategies on the European scale. The model is currently being expanded at IIASA to deal also with NO_x emissions.

The purpose of implementing RAINS at Risø is two-fold. First, the model provides a valuable supplement to the existing model ECCES in that it permits the consideration of the environmental effects of energy production at the continental scale, in particular the transboundary effects. Secondly, the familiarization with the RAINS model for Europe is a necessary preparation for the possible development of a corresponding model for Denmark or Scandinavia. Such a development would involve the use of emission data at a much greater level of geographical detail than is included in the model at present. In addition, a new transport sub-model would be required. The development of a "local" RAINS model thus provides interesting prospects for collaboration with other Risø departments as well as other Danish and foreign institutions, including IIASA.

4. Energy systems analysis

The activities of the Energy Systems Group (ESG) involve development of energy-economy models, energy and environmental planning and technical-economic assessment of energy systems and technologies.

Within the last years environmental issues have become increasingly important in the work of ESG. With a starting point in the energy system, ESG mainly treats the problem of air pollution at local and national level, and studies the possibilities of reducing emissions by energy savings, restructuring energy systems and by introducing new energy-supply technologies and renewable sources of energy.

4.1. European Commission models for energy and environment

The Energy Systems Group has for many years been responsible for the Danish implementation of models developed within the research programme for rational energy use and systems analysis of the Commission of the European Communities. During 1988 the tasks have been the implementation and scenario calculations using three models: The econometric model HERMES, the simulation model DESS, and the optimisation model EFOM with an environmental extension.

4.1.1. The macrosectoral model, HERMES

HERMES is an econometric medium-term model for determining the economic development with special emphasis on energy-economy interactions. The objective is to develop national models of similar structure for each of the EC-countries and to interlink these to create a multinational model.

In 1988 work on the Danish national model concentrated on obtaining a first workable version of the model, to deliver this to the central group of the project, to perform the first simulation and forecast experiments with the model, and to document the model.

In order to obtain a workable version of the model work has been concentrated on revising the parts of the model that raised serious simulation problems, either because the model structure had become too complex or because single equations produced very large errors. Of important simplifications in the model structure that have ben introduced it may be mentioned that the flexible KLEM-putty-clay production function has been simplified to a less flexible KLE-putty-clay production function and that this complex description of the production process is used for the industrial branches only. Another simplification introduced is that wages are now determined by an overall wage equation and simplified wage equations per branch.

The first version of the model was delivered to the central group of the project in June 1988 and since then a number of test simulations and forecast experiments have been performed. The conclusion from these simulations is that the model performs reasonably at the aggregate level. However, additional work is needed in tuning the model and revising weak parts of the model in order to obtain more accurate response at the disaggregated level.

A first version of the model is now operative and is expected to be used by the Commission of the European Communities for their economic and energy analyses. Therefore, a large part of the work in 1988 has been concentrated on documenting the present status of the model and preparing a report that may be a basis for discussions concerning the future development and application of the model.

4.1.2. The Detailed Energy System Simulation (DESS) model

While econometric models, like HERMES, are used to produce forecasts of the demand for useful energy or energy demand carriers, e.g. transport work or building volumes, the supply side may be modelled using simulation or optimisation models.

These models are demand-driven and, thus, require as input a forecast of a demand vector. The purpose of the models is to investigate a range of technology choices, forecast assumptions and investment sequences. Both economic and environmental consequences are to be analysed. One model is the Detailed Energy System Simulation (DESS) model, which is an accounting model to be used as a database for consequence calculations and presentation of results.

The energy balance of supply and demand is disaggregated to an appropriate number of conversion and end-use technologies subject to planning forecasts of their capacities. When available technologies are competing, the model will use them in "merit order", i.e. according to their variable costs. For this purpose the DESS-model includes a facility for the power system with CHP, which simulates the economic dispatch of electricity between power stations on the basis of seasonal duration curves and a merit order of the power generation units.

The original prototype for the DESS model has been used since the early 80's as the most comprehensive model for the Danish national energy planning. The idea of the model was subsequently taken up within the energy-modelling programme of the CEC. This project was started in 1985 in order to develop and extend the model into one that is able to simulate different national energy supply systems, in particular the power-generation and space-heating sectors.

The model is now implemented for Denmark, the Federal Republic of Germany and Italy, and the final report is under preparation.

The implementation for Germany was carried out in cooperation with the University of Essen, describing the structure of the German power system with emphasis on the prospects for combined heat and power. The implementation for Italy was carried out by Risø, focusing on heat demand in different climatic regions and the simulation of a power system containing both hydro electric and thermal generation. In October 1988 a seminar on the model was held at Risø with participants from CEC, the University of Essen, ENEA, Rome, and ARS S.p.a., Milan.

A software package has been developed on the VAX 8700 computer at Risø, and the portability to IBM and other computers has been established.

4.1.3. The Energy Flow Optimisation Model (EFOM)

The third model in the CEC programme is the Energy Flow Optimisation Model (EFOM), in which the energy supply system is described as a network of energy conversion and transport facilities. A linear-programming problem is set up and solved in order to disclose an optimal solution for the sequence of investment in energy-conversion and end-use technologies as well as emission-abatement measures.

The EFOM model is the supply part of the Commission's energy model complex, which has been used since the 70's. The extension of the model, which includes emissions of pollutants as well as emission abatement techniques, was developed by three West German institutes during 1986 and 1987 as part of the research project "Optimal Control Strategies for Reducing Emissions from Energy Production and Energy Use on a European Level".

This model has now been implemented for all EC countries, and various scenarios for the reduction of pollutants - in particular SO_2 and NO_x - are being studied, see Figure 4.1. The results will be published in a book that will include a report of the scenario results for each country.

Although the scenario assumptions for this multinational study are not identical to those used for the official Danish energy planning, the scenario results tend to confirm the cost-efficiency of the overall energy-planning targets. However, the most interesting result of the scenarios may be that the model prefers new "clean" technologies for power generation (e.g. integrated gasification combined-cycle power plants) instead of conventional coal-fired power plants with flue-gas treatment for SO_2 and NO_x.

The EFOM model has been implemented and tested successfully on the VAX 8700 computer at Risø.

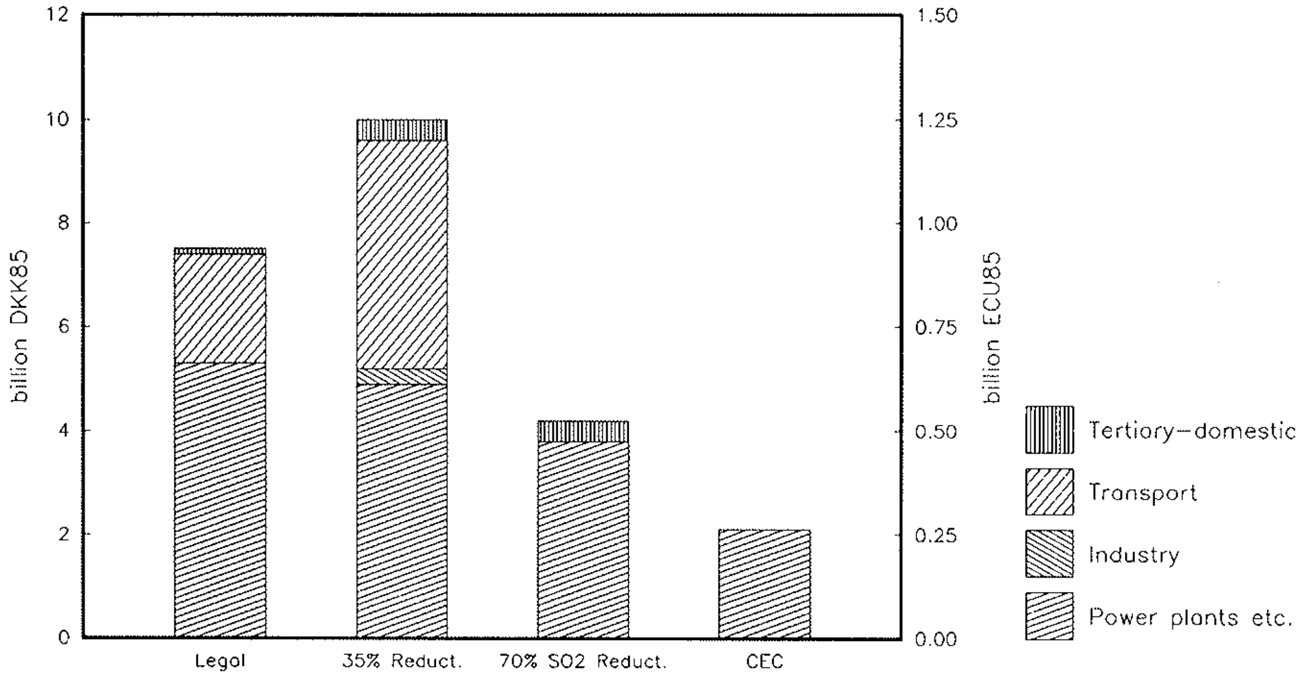

Figure 4.1. Discounted costs 1985-2010 for emission abatement measures of various scenarios for Denmark compared to a 1980 reference standard.

4.2. Simulation model for collective combined energy systems

The simulation model, SIKKE, was originally developed for the Danish Energy Agency in 1984. It was programmed in FORTRAN on Risø's Burroughs computer. An updating of the model has been completed in 1988 financed by the Nordic Council of Ministers. A standard Fortran 77 version is now running on the VAX-8700 at Risø.

SIKKE simulates with a chosen time step the operation of an energy supply system consisting of several supply technologies such as wind turbines, solar heaters, solar cells, heat pumps, diesel engines etc. An operational strategy for each unit is defined as an input and the production from each unit can be directed to the electricity grid/district heating network or to a number of storage units for electricity or heat. In order to accomplish this, several new features had to be introduced into the program. A storage unit can now be connected to each supply technology and it is possible to assign to each of these a priority which determines whether the produced energy is to be delivered first to the network or to a storage unit.

The model was tested on a number of supply systems, one of which was a small pumped storage plant on the Danish island of Bornholm. Two 95-kW wind turbines supplied electricity to the pumps at the storage tank when demand was low. The model was also used to simulate different wind-diesel systems. A simplified version of a Locus system was simulated. The system consisted here of a diesel engine, a heat pump, a wind turbine, an oil-fired burner and two heat storage units.

4.3. Technical/economic models for offshore oil and gas activities

In 1988 the work on the Sequencing Model for Oil and Gas fields (SMOG) was completed. The work was carried out in cooperation with the Christian Michelsen Institute (CMI) in Bergen, Norway, as part of a joint contract with the Danish authorities and Dansk Olie og Gas Production A/S (DOPAS).

SMOG is a comprehensive model for the offshore sector. From a detailed description of the oil and gas fields and the transport systems, and from some economic parameters, the model maximizes the net present value and points out which fields and field alternatives should be developed and when this should take place.

The SMOG system consists of two main parts: a user-interface and an optimization part. The user-interface is menu-based and was constructed by means of a general system FMENU developed at Risø which creates Fortran subroutines for menu display and user input from a definition file. The optimization part is based on parts of a general mixed-integer programming package XMP supplemented by heuristic methods. All user-specified data and optimization results are stored in a data-base for later retrieval.

During 1988 the programming was completed and a thorough testing was performed.

The SMOG system is developed for VAX and Apollo computers and installed at the Danish Energy Agency and DOPAS A/S.

4.4. Danish energy planning

The Energy Systems Group collaborates closely with the Danish Ministry of Energy and the Energy Agency.

Within the past year ESG has participated in the inter-departmental work on the Danish follow-up to the Brundtland Commission report. This report generated a great deal of interest in Denmark, and at the end of 1988 a specific report on the Danish consequences of the intentions mentioned in the report was submitted to the Danish parliament. ESG took part in this work, performing the calculations of emissions for different scenarios.

ESG contributed to the 1988 Status Report on Energy Planning by calculating the emissions of SO_2, NO_x and CO_2 from the Danish energy sector in the period 1975-2010. Emissions were calculated for each sector and for all fuel types. This was done on the basis of a set of emission factors which had been developed on request for the National Agency of Environmental Protection.

ESG undertook a study of new electricity-producing technologies on request from the Danish Ministry of Energy. The study, which was carried out in collaboration with other Risø departments involved the description of a large number of technologies with respect to their technical and economic status, development possibilities and systems implications. Among the promising technologies fuel cells, coal gasification combined-cycle plants and wind energy can be mentioned. As a supplement to the study a detailed report on fuel cells was prepared.

4.5. The channels of interdependence between the industrial and developing countries

A PhD project was initiated in 1987 concerning the channels of interdependence between the industrial and developing countries, with emphasis on the changes in the oil price.

The project consists of two parts, a theoretical part surveying existing theories describing financial and real transmission mechanisms between groups of countries, and an empirical part where models developed by the OECD are used to analyse the quantitative effects of the oil-price increases in the 70's and the following decline in the oil-price after 1980. Of other cases that may be analysed are effects of changes in the exchange rates and the international interest rate that are the main channels of financial transmissions. These transmissions have become increasingly important, especially after 1978 where we have seen a significant increase in the indebtedness of the developing countries and where the capital mobility has increased.

A main part of the empirical work is accomplished in close collaboration with OECD experts during a 6 month stationing at OECD headquarters in Paris.

4.6. Macroeconomic analysis of energy and environmental effects

A Ph.D project was initiated in 1988 to focus on the interdependence between macroeconomics, energy conversion and the consequent environmental effects.

Economic activity is the essential determining factor of energy consumption and its environmental effects. At the same time the economy is affected by environmentally induced changes in the energy system and the increasing use of abatement technologies. It is therefore important to combine the study of energy and environment with micro- and macroeconomic analysis.

As part of the programme different theories and methods and their application to analysis of the above-mentioned interdependencies is under study. Cost-benefit analysis, welfare economics, externalities in economics, and input-output analysis are some of the keywords.

Another main part of the project is the development of a model which can be used for quantification of some of the interdependencies. So far computations on the basis of an input-output model for the Danish economy in 1984 have been done in order to relate the emissions of SO_2, NO_x and CO_2 to the economic activity in the different production sectors as well as the final demand for consumption, capital formation, export etc.

4.7. Energy planning in developing countries

1988 saw the completion of a Ph.D. project on energy planning in developing countries. The study was aimed specifically at the procedures used in planning and analysing energy projects, particularly those involving energy for rural areas. The work was based on experience gained during collaboration with the Department of Energy in Zambia where a rural energy survey was carried out. The latter survey, one of the first and most detailed of its kind to be carried out in the country, was reported as the first volume of the thesis (Christensen 1985). The second volume was devoted to a specific study of energy planning procedures in Zambia (Christensen 1987).

The third volume (Christensen 1988) presented a general theoretical and empirical study of the role of project analysis in national planning efforts in developing countries. The most commonly used methods, based on cost-benefit analysis, were described in detail and their historical development and application critically discussed in relation to their theoretical, ideological and methodological basis.

On the basis of the above discussion and with the experience of the Zambian situation, a new method for project analysis was developed. This consists of a collection of programs implemented on a personal computer. These programs which use standard spreadsheet software are designed to be used in the energy planning unit of a developing country as a tool for qualitative and quantitative analysis of rural energy development projects.

4.8. Absorption cooling

Almost all cooling in Denmark is provided by electrically driven compressor units. A few installations, however, use absorption machines. Such machines can utilize surplus heat from combined heat and power (CHP) plants, incinerators, and industry. A substitution of compressor units by absorption units would result in lower electricity consumption, especially in the summer, and a levelling off of heat consumption.

A project has been carried out in collaboration with the Engineering and Electronics Departments at Risø, Copenhagen County Hospital at Herlev and Sabroe A/S. The purpose of the project has been to study the potential use of absorption cooling and to give a quantitative estimate of the profitability. A final report will be issued in early 1989.

The main conclusions are:

- For a great number of applications the primary energy consumption for absorption cooling driven by CHP-heat and compression cooling driven by electricity will be approximately equal.
- Absorption cooling for air-conditioning will only be economically attractive for rather big plants (design cooling load more than 600 kW).
- If an absorption cooling plant is powered by true surplus heat which otherwise not would be used, there is both an energy and economic advantage.

The amount of surplus heat at sufficient temperature (100°C) in Denmark is declining and unfortunately the colocation of such surplus heat and cooling requirement is rare.

4.9. Environmental planning

The following three projects are concerned with planning aspects of energy and the environment. In each case the aim is to develop tools which can be used in the decision making process to link emission reductions and the planning of energy supply and consumption.

4.9.1. A model for analysing environment-driven investments in the Danish space-heating sector

A model has been developed to analyse the economic and technical possibilities for reducing emissions of SO_2, NO_x , CO, CO_2, PAH and particles in sections of the space-heating sector in Denmark. The project is financed by the Danish Building Agency and considers particularly energy conservation action.

The approach is based on well-defined building categories and reference heating and insulation technologies commonly used in Denmark. A number of alternatives are set up and difference project calculations are done taking into account energy consumption, emissions to the environment and economy. These basic scenario elements are combined, sorted and accumulated according to given criteria to build up a number of overall scenarios which cover sections of the space-heating sector.

The main results are relations between investments and emission reductions for the various alternatives and scenarios. The project will be completed in 1989.

4.9.2. Study of methods and models for environmental impacts of energy systems in the Nordic countries

Existing models and methods used for integrated energy and environment planning in the Nordic countries are investigated in a project sponsored by the Nordic Council of Ministers. The project was initiated in 1988 and is expected to be completed in 1989.

The strengths and weaknesses of the models and methods are analysed in relation to the following subjects:

- The impact on natural resources, human wellfare and health, buildings and monuments etc. by the energy system.
- Comparison of alternative energy conversion systems.
- Principles for evaluation of environmental benefits.
- Management strategies.

An important aim of the project to provide recommendations about how the social costs of the energy systems can be fully integrated into the energy planning procedure in order to treat the energy related environmental problems. Furthermore the project includes an evaluation of the possibilities for common research and development in the Nordic countries especially on the economics of environmental impact.

4.9.3. Integrated energy and environmental planning

A project group consisting of Cowiconsult, The Technical University of Denmark, the Danish Energy Agency and Risø has been formed in order to study the coupling between energy-use and the resulting environmental impact. The goal is to forecast the consequences of possible changes of the energy-system with regard to pollution on a regional scale.

The following compounds have been taken into account as the most important pollutants: SO_2, NO_x, PAH, heavy metals and CO_2. As a measure of pollution, the amount of emission of a given compound is related to that level (the critical load) below which the conditions in nature are tolerable in that region.

The work carried out by ESG is an improvement and expansion of the energy information system at the Danish Energy Agency to include computations of pollutant emissions. This involves, for example, for a given size of a house with a specified age and heating system, the calculating of fuel consumption and thus the emissions. The work was initiated in 1988 and will be finished in 1989.

4.10. CORINAIR

CORINE (**Co**-**OR**dinated **IN**formation on the **E**nvironment in the European Community) is an experimental programme of the Commission of the European Communities, managed by DGXI, the Directorate-General for the Environment, Consumer Protection and Nuclear Safety.

The purpose of this programme is twofold. Firstly, it is intended as the means to develop a methodology for the collection, storage and analysis of data describing the state of the environment throughout the member states of the Community. Secondly, it is designed so as to produce results which are of immediate practical utility in the Commission's task of responding to specific environmental problems.

CORINE is composed of several projects consistent with each other and conducted in parallel on the following topics: biotopes, emissions to the atmosphere (CORINAIR), ground covering, soil erosion and resources in important zones, water resources, coastal erosion, marine environment, seismic risks and ground pollution.

The objective of CORINAIR is the achievement of an inventory of atmospheric pollutant emissions in Member States of EC.

In 1988 ESG became responsible for the Danish part of the inventory. The inventory will later be expanded with other pollutants and possibly into smaller territorial units the size of Danish municipalities.

4.11. Sewage treatment plant

The number of sewage treatment plants in Denmark which include removal of nitrogen nutrient salts will increase considerably during the next few years. The majority of plants will use the bacteriological nitrification (conversion of ammonia to nitrate) process, which is very sensitive to temperature. At water temperatures below 6-8°C the process nearly stops, causing nitrogen concentration limits in the effluent to be exceeded. The ultimate solution would be to heat the water in order to maintain the process, but since the critical temperature is reached in many plants during winter, heating would be both energitically and economically unfeasible.

The process temperature in the plant is a result of the incoming water temperature and the heat loss or heat gain of the plant. A large number of parameters are involved, for example the amount of surface water, the weather, tank surface area etc.

A project was initiated in 1988 in collaboration with I. Krüger A/S with the aim of investigating the causes of low process temperature and possible remedies. The project is part of the Danish Energy Research Programme 1988 (EFP 88).

The first part of the project will be a measurement program for the winter 1988/89 covering 10-15 plants of varying size, construction and type of sewage system. The collected data will form the basis for the subsequent analysis.

4.12. The Great Belt Fixed Link: consequences for energy use and emissions

In 1987 the Danish parliament passed an act setting down the principles for the construction of a fixed link across the stretch of water known as Storebælt or the Great Belt. This stretch of water, 18 km wide, separates the population and industry of the country into two halves. At present connection across the belt is by means of road and rail ferries.

In 1988 the Energy Systems Group carried out a study of the consequences for energy consumption and the associated emissions of building such a fixed link. It was assumed in the study that both a motorway and a rail connection would be operational in 1996 and this situation was compared with a base case with no fixed link, retaining the present ferry system.

The calculations were based on projections of the expected traffic between east and west Denmark in 1996. These projections assume a discontinuous increase in traffic across the Great Belt when the fixed link is established. They also assume a certain transfer of traffic from other ferry routes, particularly across the Kattegat, and from domestic air transport. A number of scenarios corresponding to different traffic growth rates were analysed.

Energy use was calculated by multiplying the traffic by each mode of transport by appropriate figures for specific energy consumption, i.e. amount of energy per transported person or ton goods per unit distance. Similarly the levels of emission for relevant pollutants, CO, NO_x, SO_2, etc., were calculated.

Since both specific energy consumption and emission factors are subject to large uncertainty, it is difficult to obtain precise values for the changes when comparing different modes of transport. In addition there are various uncertainties built into the traffic projections, not least the extra distance to be associated with new and transferred cross-belt trips. Nevertheless the study was able to conclude that an energy saving of 2 to 3 PJ per year could be expected in comparison to the situation in which the present ferry system was retained. This energy saving is primarily due to the transfer of traffic from ferries to road and rail, bearing in mind that ferry transport is between five and ten times as energy consuming per transported unit as land transport.

Corresponding reductions in the emission of pollutants can also be expected compared to the present ferry-based system.

In addition to the calculation of energy consumption of east-west traffic, an estimate was made of the energy consumption associated with the building of the fixed link, compared with the energy necessary in the corresponding basis alternative which involved the construction of new ferries.

The energy analysis was based primarily on energy intensities for the appropriate industries (construction, shipbuilding) and materials (concrete, steel) and was naturally subject to considerable uncertainty. The conclusion, however, was that the energy consumed in constructing the fixed link would be "repaid" by the energy savings from traffic within between three and six years.

A second phase of the study was initiated in the latter half of the year. This had the object of clarifying certain uncertainties in the calculation, introducing updated emission factors and, in general, ensuring broad acceptance among relevant authorities for the parameters used in the study.

4.13. Wind energy

As one of the mature renewable energy technologies wind energy has a growing interest. A recent study (Morthorst et al. 1987) performed by the Energy Systems Group shows that wind-produced electricity might be nearly competetive with electricity produced at conventional power plants, especially if environmental consequences are taken into account.

In collaboration with the Test Station for Windmills at Risø, the Energy Systems Group has carried out a survey in order to improve the basis for the calculation of the production costs for electricity produced by wind turbines. The aim of the survey is to obtain actual figures for repair and maintenance, investment costs, the annual electricity production of the turbine, social and environmental benefits and/or problems etc. More than 800 questionnaires were sent out and a little more than 300 had responded by the end of the year. During the autumn the data from the questionnaire were put into a database using the SAS-software, and a large number of analyses performed. A report is expected to be published in the spring of 1989.

5. Publications, Lectures and Conferences

5.1. Conferences

In 1988 the planning of an international conference was started. The conference is entitled Environmental Models: Emissions and Consequences, and is planned to take place at Risø 22-25 May 1989. The Commission of the European Communities accepted to sponsor the conference and an International Programme Committee was set up. Call for papers was issued medio 1988 and deadline for abstracts of proposed papers was 1 November. On its meeting in December the programme committee finalized the preliminary programme of the conference.

The conference will address both the basic scientific aspects of model development and experience with practical applications of environmental models, e.g. in public planning and administration.

The conference will aim at bringing together scientists, economists and decision makers with a mutual interest in the planning of emission reductions and alleviating the damage to the environment.

The conference is organised in a number of sessions dealing with:

- emissions
- emissions and short-range effects
- economics
- biological effects
- aquatic systems
- terrestrial systems
- integrated models
- energy and environmental planning.

Altogether there will be 43 oral presentations, of which a number will be invited keynote papers. In addition a number of papers will be presented as posters.

5.2. Publications

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Bjørnestad, S., Helgesen, C., Larsen, H.V., Christensen, P. Skjerk. (1988). Smog User Interface: Design Description, Version 2. Confidential.
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Christensen, J.M. (1988). Project Planning and Analysis. Methods for Assessment of Rural Energy Projects in Developing Countries. Risø-M-2706. 160 pp.
Energisystemgruppen (1988). Energi- og emissionsundersøgelse for en fast forbindelse over Storebælt. (Forskningscenter Risø. Energisystemgruppen, Roskilde) 91 pp.
Grønberg, C.D. (1988). Stor enighed om mangler i risikovurdering (Broad agreement on the shortcomings of risk analysis). Miljø Teknologi 3 (4), p. 102-103.
Grønberg, C.D. (1988). Er beredskabet forsvarligt? (Is preparedness defensible?). Nyhedsbrev Teknologinævnet (no. 8) p. 27-29.
Morthorst, P.E., Hjuler Jensen, P. (1987). Samfundsøkonomi for vindmøller. Status og perspektiver for vindmøller opstillet i Danmark. (Economics of wind turbines) Risø-M-2697. 64 pp.
Nielsen, M., Ott, S. (1988).HEAVYPUFF. An Interactive Bulk Model for Dense Gas Dispersion with Thermodynamical Effects. Risø-M-2635. 27 pp.
Petersen, K.E. (1988). Computer Aid in Safety Analysis and Risk Management. In: Seminar for the Industrial Installation Inspectors of the Member States. Copenhagen, 8-10 June 1988. (Danske Ingeniørers Efteruddannelse, DTH, Lyngby) 11 pp.
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5.3. Lectures

Grohnheit, P.E. Introduction of CHP/DH in closely built urban areas: A dynamic model approach. 28 April 1988, Seminar at Science Policy Research Unit, University of Sussex, Brighton, UK.
Grohnheit, P.E. Environmental effects of energy production. Objectives and measures. A survey of Danish experience and legislation. 17-19 May 1988, joint Portuguese-Danish seminar on energy planning, Coimbra, Portugal.
Halsnæs, K. The development of energy system models at Risø and the relevance of these in environmental planning. 16 May 1988, Roskilde University Centre.
Jensen, N.O., Ott, S. and Smith-Hansen, L. Udslip og spredning af gasser (Release and dispersion of gases). 30 November-1 December 1988, University of Lund, Sweden.
Petersen, K.E. and Rasmussen, B. Risiko og pålidelighedsanalyse (Risk and reliability analysis), 15 February 1988, Roskilde University Centre.
Petersen, K.E. Risikovurdering (Risk evaluation). Information meeting on current prospects concerning timber impregnation, 15 April 1988 Hotel Nyborg Strand.

Petersen, K.E. and Rasmussen, B. Risiko og pålidelighedsanalyse (Risk and reliability analysis), 15 February 1988, Roskilde University Centre.
Petersen, K.E. Risikovurdering (Risk evaluation). Information meeting on current prospects concerning timber impregnation, 15 April 1988 Hotel Nyborg Strand.
Petersen, K.E. Forsyningssikkerhedsanalyse af Nybro (Security of supply analysis for Nybro) 29 September 1988, Dansk Ingeniørforening Society for Risk Evaluation, Nybro.
Rasmussen, B. Uønskede kemiske reaktioner - thermisk stabilitetstest (Unwanted chemical reactions - thermal stability tests) 15 February 1988, Dansk Ingeniørforening.
Rasmussen, B. Hvorledes foretages en risikoanalyse? (How is a risk analysis carried out?) 10 March 1988, Course on social mediance. Sundhedsstyrelsen (National Board of Health).
Rasmussen, B. Når risikoanalyse bliver offentlig (When risk analysis becomes public). 30 May 1988, Course for journalists. Industrirådet (Federation of Danish Industries).
Rasmussen, B. Uønskede kemiske reaktioner (Unwanted chemical reactions). 31 May 1988, Arbejdstilsynet (Danish Labour Inspection Service).
Rasmussen, B. Risikoanalyse af automatiserede anlæg (Risk analysis of automated equipment). 3 June 1988, Arbejdsmiljøinstituttet (Danish National Institute of Occupational Health.
Rasmussen, B. Risikoanalyse af trykimprægneringsanlæg (Risk analysis of vacuum pressure impregnation equipment) 23 November 1988, Seminar on fire and the environment arranged by Dansk Brandværnskomité (Danish Fire Protection Association).

5.4. Participation in committees, etc.

The Department is represented in a number of national and international committees, steering groups etc. Examples of these are:

Danish

1. Research committee for industrial processes and products (Min. of Energy).
2. Steering group - scenarios for energy consumption in transport.
3. Electricity forecasting group (Min. of Energy).
4. Steering group - Staff Training and Institutional Strengthening (Danish Energy Agency).
5. Inter-ministerial committee on energy policy in the EC (Min. of Energy).
6. Export coordination committee (Min. of Energy).
7. Risk assessment committee (Academy of Technical Sciences).
8. Steering committee, Danish Society for Risk Assessment.
9. Environmental Appeal Board.
10. V.E. data.

International

1. Organizing committee for IEA-Workshop on long range research opportunities.
2. Ad hoc expert group on energy systems analysis (Commission of the European Communities).
3. CGC5 Nuclear fission energy, safety (C.E.C.).
4. Steering committee, Society of Reliability Engineers, Scandinavian Chapter.
5. Steering committee, European Safety and Reliability Association.
6. Editorial board, Journal of Loss Prevention in the Process Industries.
7. Danish representation on International Group of Experts on Explosion Risks of Unstable Substances (OECD).
8. RAS/NKA Steering committee.
9. International Programme Committee for the conference on »The systems approach to environmental and natural resources management in the Baltic region«, Leningrad, November 1989.
10. Scientific Advisory Panel, First International Conference on Loss of Containment.
11. Editional board, Nuclear Instruments and Methods, Section A.
12. Committee for European Standards on Nuclear Electronics.

6. Staff

Hans Larsen, M.Sc. Elec. Eng., Ph.D. in Reactor Physics in 1973. From 1973 to 1976 at Dragon project at AEE Winfrith, U.K. Risø from 1976. Energy Technology Department 1976-80, working with systems reliability. Head of Energy Systems Group 1980-84. Head of Department from 1985.

Energy Systems Group

Poul Erik Morthorst, M.Econ. Economist specialized in econometrics and macro-economics. Risø from 1978. Main activities: General energy planning with emphasis on forecasting electricity demand. Economics of renewable energy techno logies, especially wind turbines. Head of Energy Systems Group from 1985 and deputy head of department.

Jørgen Fenhann, M.Sc. Physicist with mathematics and chemistry as subsidiary subjects. Niels Bohr Institute 1977. Risø from 1978. Main activities: Energy planning, economics of new and renewable energy technologies, energy planning for developing countries, and computer simulation. Deputy head of Energy Systems Group.

Frits Møller Andersen, M.Econ. Specialized in econometrics and macro-economic modelling. Research assistant Århus University 1978. Assistant planner in local government 1979. Risø from 1980. Main activities: The macro-sectoral model HERMES for Denmark and a technical-economic model for the Danish industrial energy consumption.

John Møbjerg Christensen, M.Sc. Eng. Ph.D. National Agency of Technology 1980-83, R&D initiation and administration for Council of Technology, Oilconsult 1983-84, R&D Energy Planning. Risø from 1984 until 1988 working on Ph.D. project: Assessment methods appplicable to energy projects in rural areas in developing countries. From August 1988 on leave from Risø, working as Junior Professional Officer at United Nations Environmental Programme headquarters in Nairobi, Kenya.

Peter Skjerk Christensen, M.Sc. Elec. Eng. Risø from 1958. Nuclear research and education (1958-69), reactor engineering and thermo hydraulics including simulation models (1969-76), Energy Systems Group from 1977. Main activities: Energy systems modelling.

Poul Erik Grohnheit, M.Econ. Danish Building Research Institute 1969-71, town planning consultant 1971-72 and 1979-80, budgetting and economic planning at local government 1973-79. Risø from 1980. Visiting fellow at Science Policy Research Unit, University of Sussex, UK, March-April 1988. Main activities: Energy system simulation model, power system economics, and environmental modelling.

Kirsten Halsnæs, M.Econ. Danish Ministry of Housing and Building 1983-1987. Risø from April 1987. Main activities: Energy system simulation model, energy and environmental economic models, emission calculations for the Danish energy system.

Niels A. Kilde, M.Sc. Chem. Eng. The Danish Steelworks Ltd. 1962-81. Research and quality control (1962), planning and administration (1967), casting dept. manager (1972), development and energy manager (1977). Risø from 1981. Member of the steering group for R&D in industrial processes of the Ministry of Energy.

Helge V. Larsen, M.Sc. Elec. Eng., Ph.D. The Technical University of Denmark 1974. Storno A/S from 1975: development of VHF/UHF equipment. Risø from 1976. Department of Reactor Technology 1976-77. Energy Systems Group from 1977. Main activities: CHP production, modelling of energy systems, economic models for the oil and gas sector.

Michael Madsen, M.Sc. Mech.Eng. Technical University of Denmark 1982-83. B. Korsholdt Christensen A/S, Consulting Engineers 1983-87. Risø from 1987. Main activities: Assessment of energy technologies and computer simulation.

Lars Henrik Nielsen, M.Sc. Phys., Math. Risø from 1981. Main activities: Probabilistic methods and model development, technical-economical modelling, assessment of energy technologies, energy conservation, and forecast modelling.

Risk Analysis Group

Per E. Becher, M.Sc. Mech. Eng. Airforce equipment command 1970-71. Risø from 1971. Department of Energy Technology 1971-84. Risk Analysis Group from 1984. Main activities: Structural reliability, reliability and safety analysis of nuclear plants, and safety analysis of industrial plants. Head of Risk Analysis Group.

Kurt Erling Petersen, M.Sc. Ph.D. Risø from 1977. Department of Energy Technology 1977-84. Risk Analysis Group from 1984. Main activities: Development of computer codes for reliability analysis, development of tools for operation and maintenance, and treatment of reliability data. Deputy head of Risk Analysis Group.

Palle Christensen, M.Sc. Elec. Eng. Risø from 1962. Electronics Department 1962-86 working on nuclear instrumentation, research instrumentation and reliability projects. Department of Information Technology 1986-88 working on knowledge-based computing. Secretary of Risø's patent council 1973-88. Risk Analysis Group from 1988. Main activity: Development of computer codes for reliability and safety analysis.

Ernest C. Fuller, M.Sc. Chem. Eng. University of Idaho (USA) 1985-86, R&D (unit operations, process simulation and optimization). Risø from 1987 until 1988.

Carsten D. Grønberg, M.Sc. Elec. Eng. Risø from 1967. Electronics Department 1967-78. Safety Department 1978-83. Risk analysis Group from 1984. Main activities: Human factors, emergency planning, risk management.

Jens Ole Knudsen, M.Sc. Chem. Eng. Risø from 1987. Main activities: Dynamic computer-simulation and physical modelling of release, fire, explosion and dispersion of substances from a chemical process plant.

Hans E. Kongsø, M.Sc. Mech. Eng. Risø from 1957. Research reactor DR 2 1957-63, Department of Energy Technology 1963-84. Risk Analysis Group from 1984. Main activities: Computer codes for reliability and consequence assessment, and risk assessment of nuclear and industrial plants.

Jens Peter Madsen, B.Sc. Chem. Eng. Risø from 1988. Main activities: Computer-sumulation and physical modelling of release, fire and dispersion of substances from chemical process plant.

Birgitte Rasmussen, M.Sc. Chem. eng. Ph.D. The Technical University of Denmark from 1981-84. Risø from 1984. Main activities: Risk assessment of chemical plants, chemical process hazard identification, assessment toxic effects from releases, and development of guidelines for risk analysis of offshore installations.

Lene Smith-Hansen, M.Sc. (Chemistry). Risø from 1986. Main activities: Risk assessment of chemical plants, toxic effects from releases, and quantitative assessment of toxic chemical substances from combustion.

Environmental Modelling Group

Gordon A. Mackenzie, B.Sc. Ph.D. (Physics). Guest researcher at Risø 1974-78. Lecturer at Edinburgh University 1978-79. Energy Systems Group from 1980 working mainly on energy demand models. 1984 to 1987 Energy Adviser/Deputy Director at Department of Energy, Zambia on contract with Danida. From February 1988 leader of Environmental Modelling Group. Main activities: environmental impact models, energy use and environmental impact of transport, energy in developing countries.

Helle Christiansen, M.Sc. (Pharm.). Risø from 1986. Department of Energy Technology 1986-88. Joined Systems Analysis Department February 1988. Main activities: Development of environmental impact models.

Klaus Haahr Jørgensen, M.Sc. (Chemistry). MLKE-Næstved 1986-87. Risø from 1987. Department of Energy Technology 1987-88. Joined Systems Analysis Department February 1988. Main activities: Development of environmental impact models.

Postgraduate students

Per Andreasen, M.Sc. Chem. Eng. Risø from March 1988. Subject of Ph.D. research project: Hazard identification at plant level.

Søren Ott, M.Sc. Phys., Math. Risø from 1985. Main activities: Models and computer codes for consequence assessment; real time simulation of blow-downs, plume formation, and gas explosions. Ph.D. student from 1987, subject: Micrometeorological aspects of risk assessments.

Ole Gravgård Pedersen, M.Econ. specialized in macro-economics and economic modelling. Worked in the Institute of Agricultural Economics on input-output models. Risø from March 1987. Main activities: energy and environment, implementation of the CEC energy and environment linear programming model EFOM. Started Ph.D. programme 1988, subject: Macro-economic analysis of energy and environmental effects.

Sverrir Sverrisson, M.Econ. Risø from 1985. Main activities: Macro-economics, econometrics and international economics, development, and implementation of the CEC macro-sectoral model HERMES. Started Ph.D. programme January 1987. Subject: The channels of integration between the industrial and the developing countries.

Temporary staff

Imad Amin, B.Sc. (chemistry). Risø from June 1987 until June 1988.

Consultant

Peter Laut, Professor, Engineering Academy of Denmark.

Programmers

Maria Sonia Cárdenas Alvarado. Born in Chile. Educated programmer 1986 in Denmark. Risø from March 1987. Working on the event modelling program.

Ulla Dollerup Hansen. Educated 1987. Risø from 1987. Computer programs for consequence modelling, and safety and reliability.

Søren Præstegaard, datanom. Regnecentralen 1973-79. Risø from 1979. Datanom with special subject: Optimization completed 1985 at EDP-school, Copenhagen. Working on simulation models and graphics.

Einar Danielsen. Risø from 1985. Temporarily assigned to Systems Analysis Department from February 1988. Working on development of environmental impact models.

Secretaries

Maria M. Andreasen
Gytha Egelund
Kirsten G. Hansen
Jette Larsen
Irma Strandvad

Undergraduate assistants

Jesper Schmaltz-Jørgensen
Henrik Sørensen
Kim Michael Eriksen

7. References

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Bibliographic Data Sheet **Risø-R-565**

Title and authors

Systems Analysis Department
Annual Progress Report 1988

Edited by Hans Larsen and
Gordon Mackenzie

ISBN	ISSN
87-550-1487-9	0106-2840 0903-7101

Dept. or group	Date
Systems Analysis Department	March 1989

Groups own reg. number(s)	Project/contract no.

Pages	Tables	Illustrations	References
31		4	3

Abstract (Max. 2000 characters)

The report describes the work of the Systems Analysis Department at Risø National Laboratory during 1988. The activities may be classified as energy systems analysis, risk and reliability analysis and environmental modelling. The report includes a list of staff members.

Descriptors INIS/EDB

ENERGY MODELS; ENERGY SYSTEMS; ENVIRONMENT; PROGRESS REPORT; RELIABILITY; RESEARCH PROGRAMS; RISK ASSESSMENT; RISOE NATIONAL LABORATORY; SYSTEMS ANALYSIS; TECHNOLOGY ASSESSMENT

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